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UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Localization

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Computer Networks and Telematics
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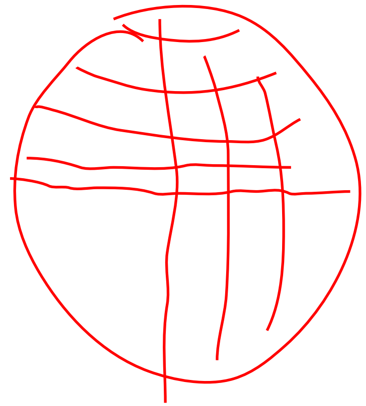
CoNe Freiburg

IIF
INSTITUT FÜR INFORMATIK FREIBURG

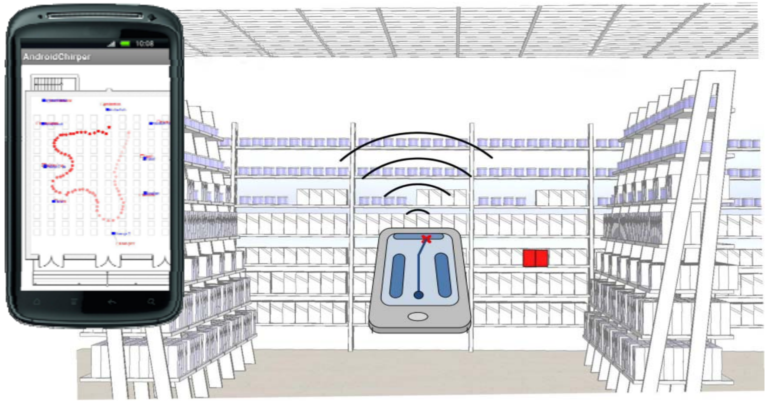
Localization



- **Localization in an empty environment?**
  - **Requires some “stuff” around**
  - **Determine the physical position or logical location**
- **Reference points (“landmarks”)**
  - **Natural: Trees, mountains, river bend, earth’s surface, sun, stars, ...**
  - **Artificial: Road signs, Surveyor’s mark, Retro-reflector, buoys, lighthouse, radio beacon, ...**
- **Coordinate systems**
  - **Global coordinate frame, Earth coordinates**
  - **Local reference frame: Cartesian grid, floor tiles**
  - **Absolute or relative coordinates**

Localization

- Applications
  - Surveying, geodesy
  - Naval navigation, aviation, space flight
  - Navigation of people inside buildings in urban areas
  - Cars on roads, logistics
  - Navigation of robots: Autonomous mobile units
  - Industrial machines, tools: Drills, rivet hammers
  - Networks: Routing algorithms, sensor networks
  - ...and many more!



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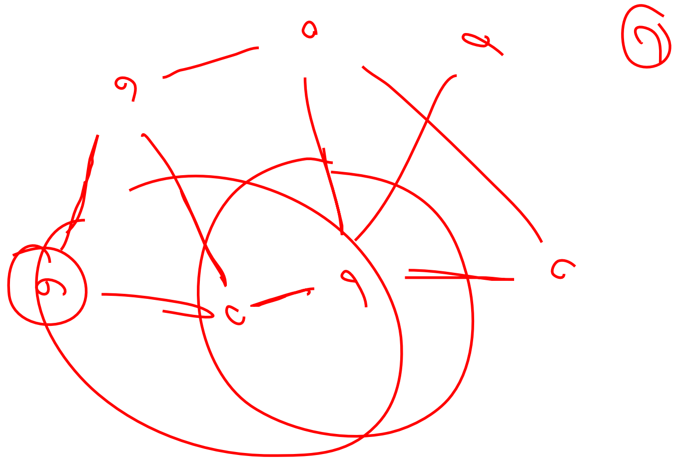
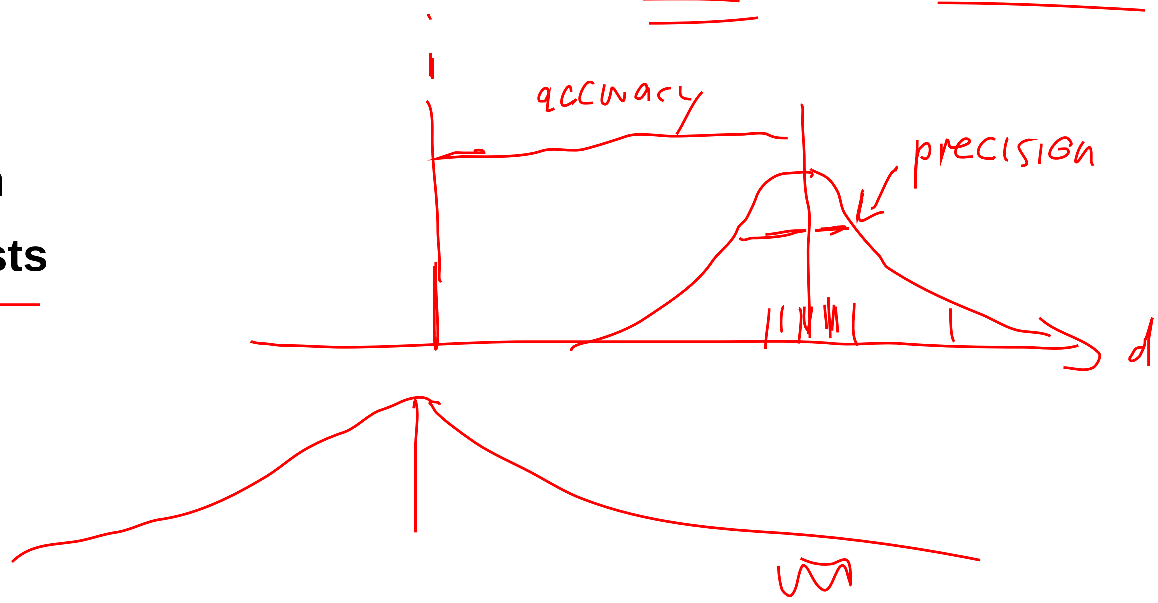


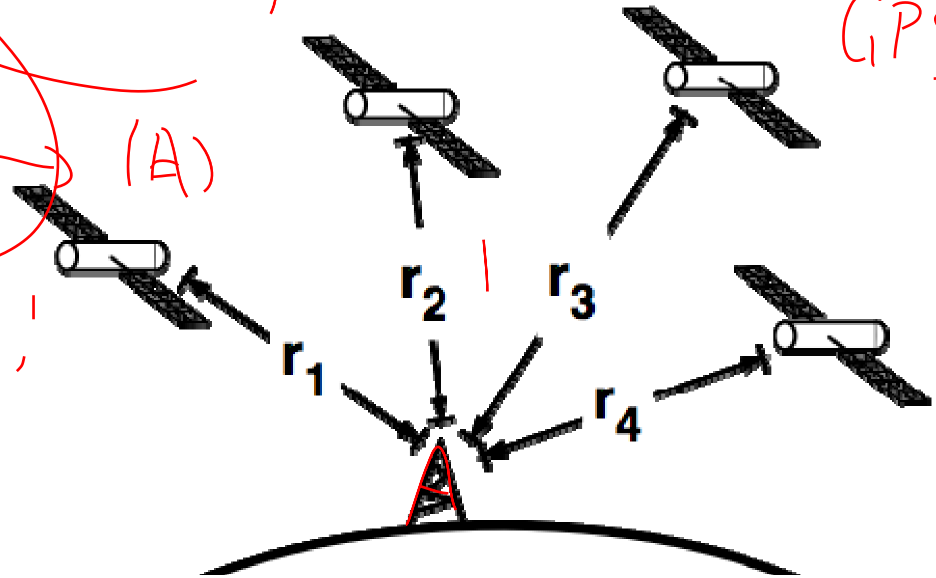
- **Parameter**
  - **Centralized or distributed computing**
  - **Availability of position information: Active vs. passive localization**
  - **Application**
    - **Indoors, outdoors, global**
  - **Sources of information: Sound, light, radio signal, magnetic field, ...**
- **Metrics**
  - **accuracy**
  - **precision**
  - **other costs**

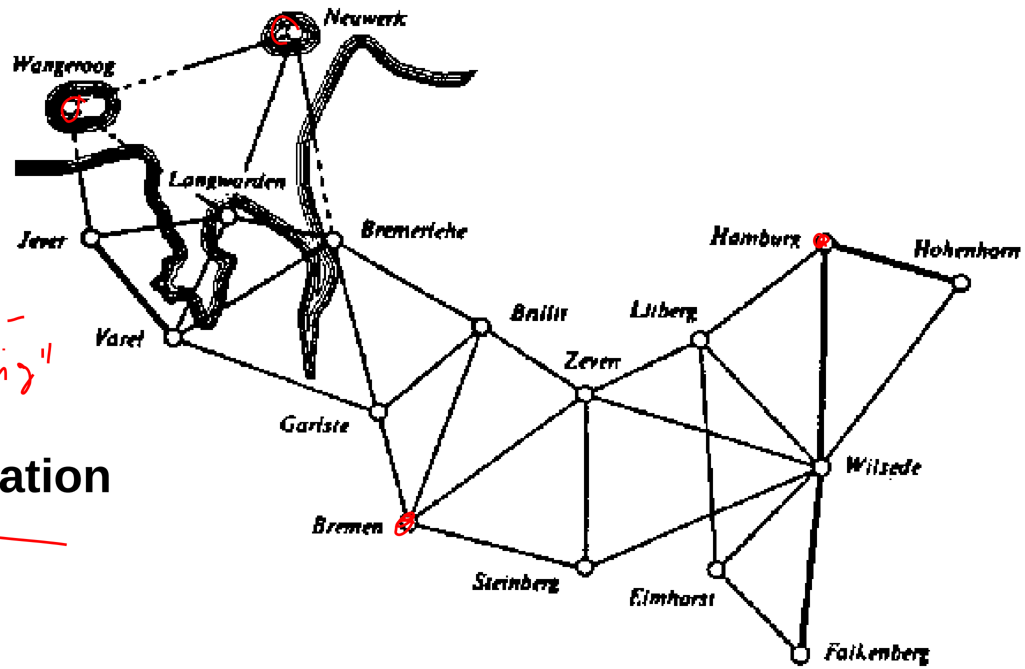


Sources of Information

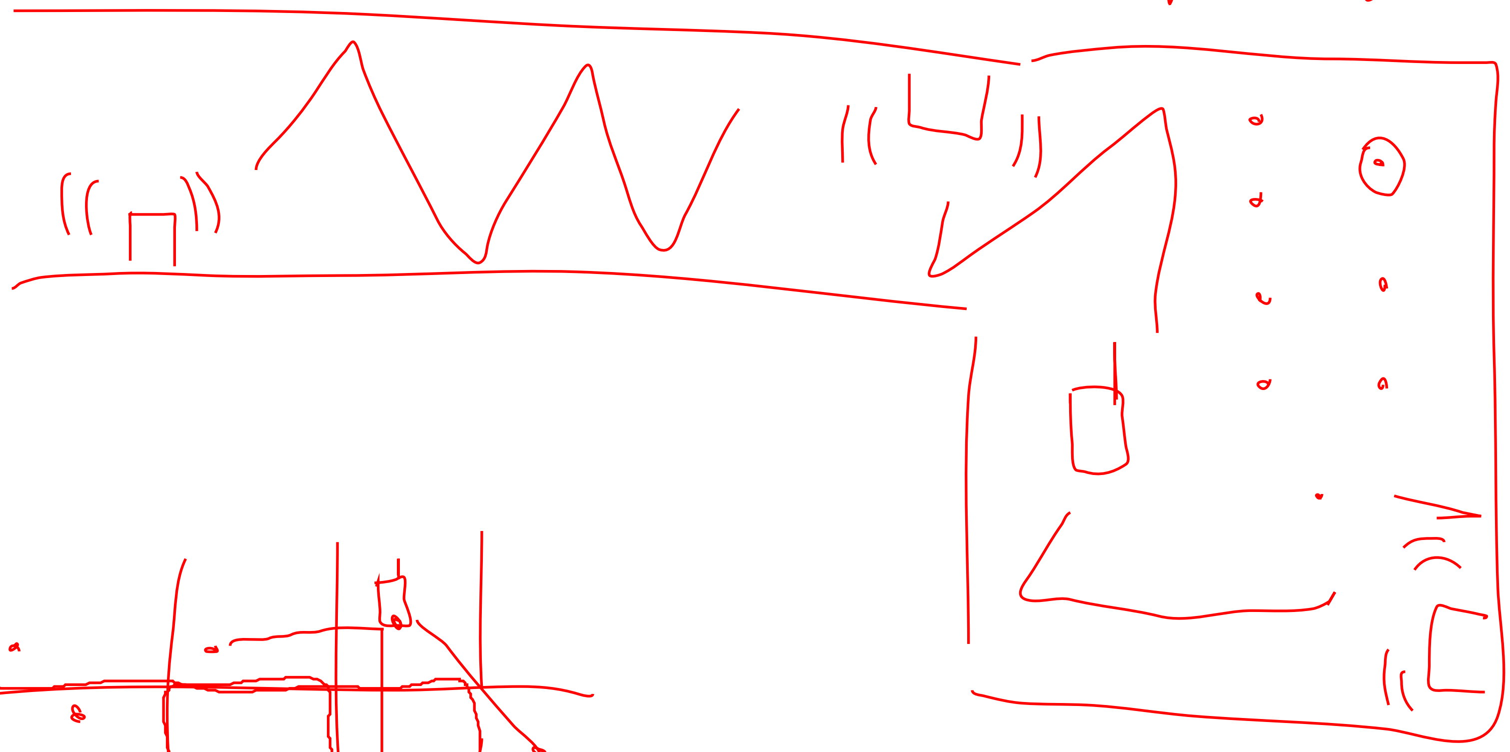
- Neighborhood information
  - Range provides coarse location information
    - e.g. GSM / UMTS cell, wireless IDs
- Triangulation and trilateration
  - Angle differences
  - distance measurement
- Analysis of the environment
  - Characteristic "signature" by radio conditions in the environment „Finger-printing"
- Inertial navigation systems
  - Measurement of acceleration and rotation

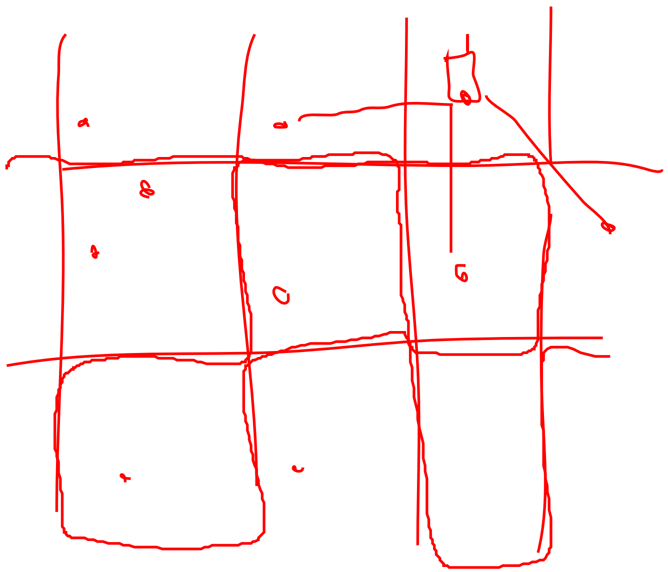
GPS



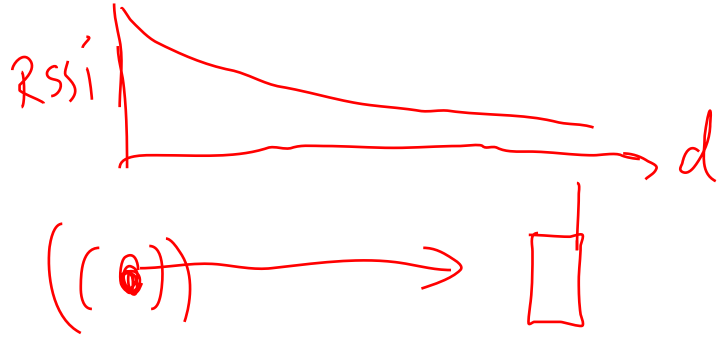


Fingerprinting





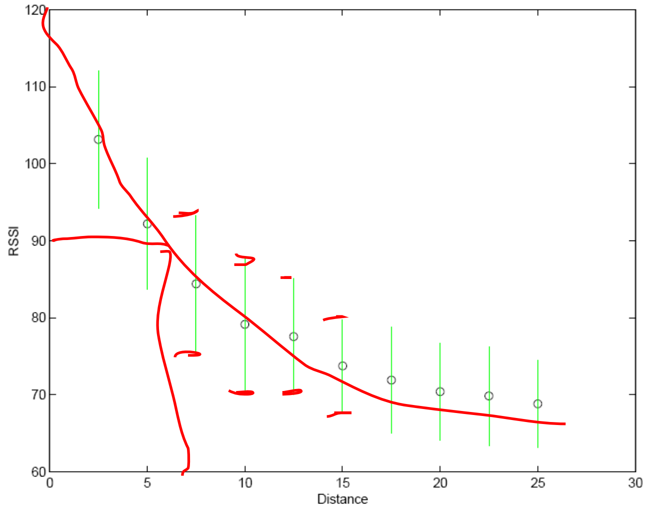
RSSI



- **Received Signal Strength Indicator**
  - **Using the path loss at a known transmission power**
  - **Measurement of the received signal**

$$P_{\text{recv}} = c\frac{P_{\text{tx}}}{d^{\alpha}} \Leftrightarrow d = \sqrt[\alpha]{\frac{cP_{\text{tx}}}{P_{\text{recv}}}}$$

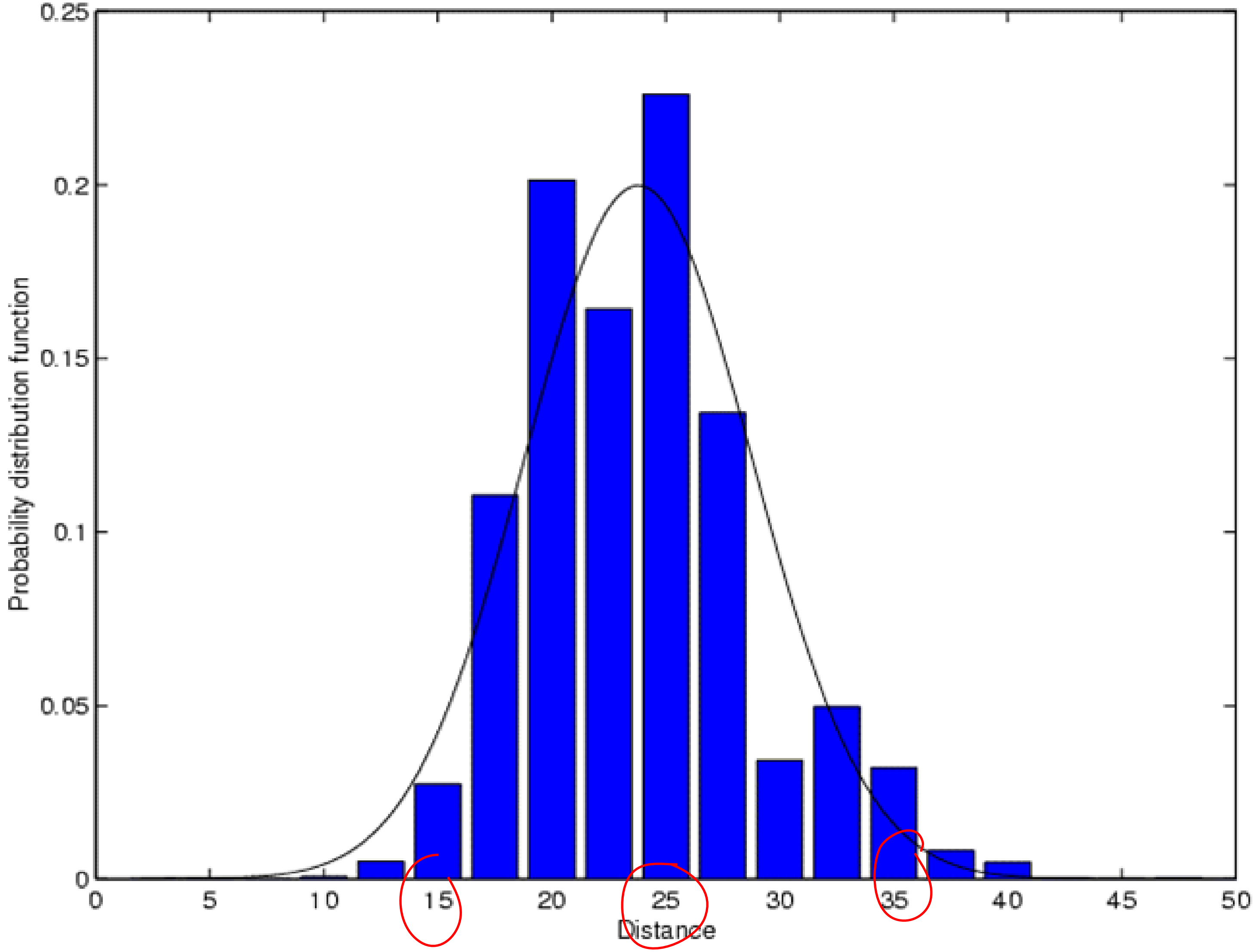
  - **Path loss exponent α, transmission power P_{tx}**
  - **Problem: High error rate**



[Sichitiu and Ramadurai, MASS 2004]

RSSI

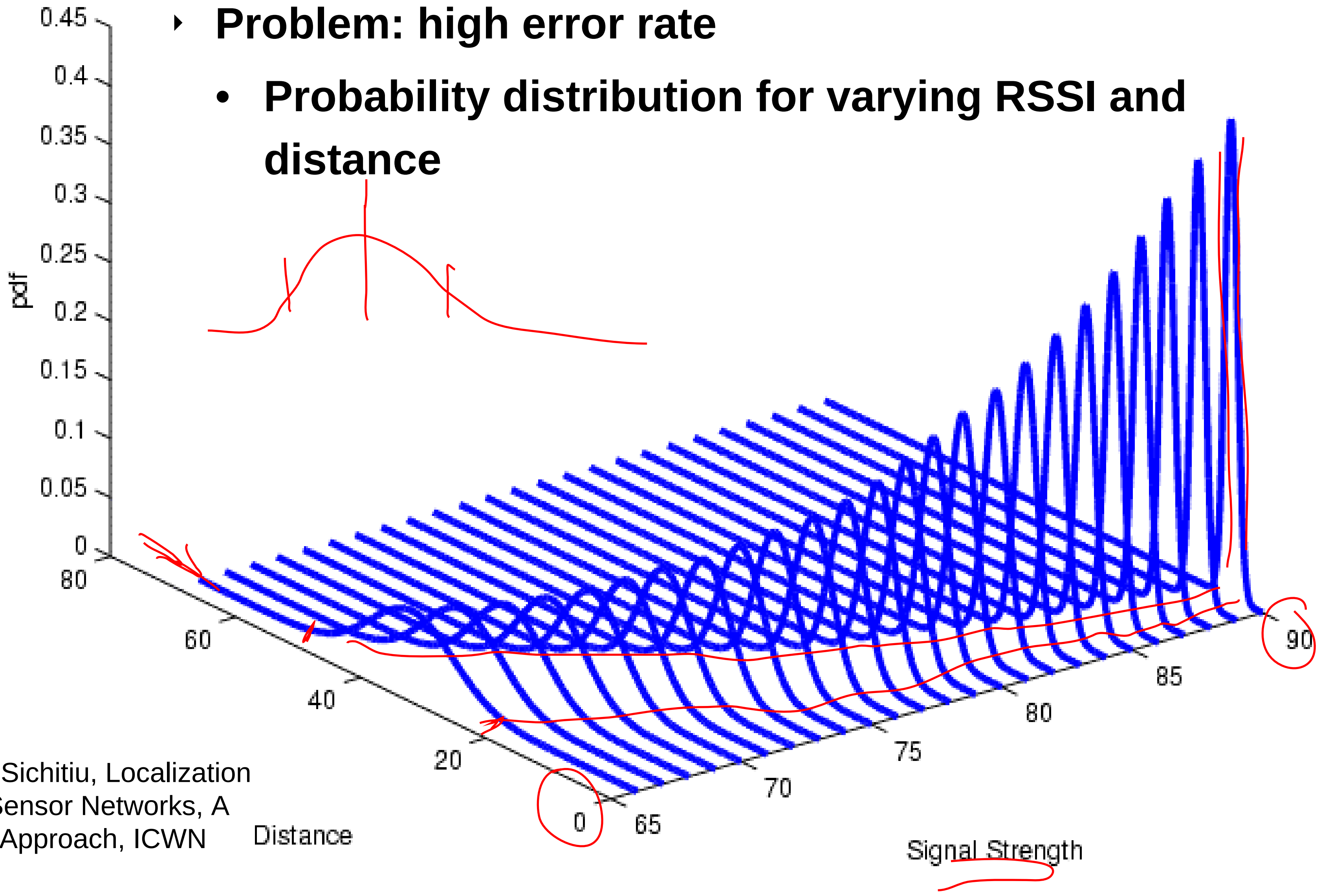
- **Problem: high error rate**
  - **Probability distribution for RSSI and given transmission power**



[Ramadurai, Sichitiu,
Localization in Wireless
Sensor Networks,
A Probabilistic Approach,
ICWN 2003]

RSSI

- **Problem: high error rate**
  - **Probability distribution for varying RSSI and distance**



[Ramadurai, Sichitiu, Localization in Wireless Sensor Networks, A Probabilistic Approach, ICWN 2003]

RSSI

- **Problem: high error rate**
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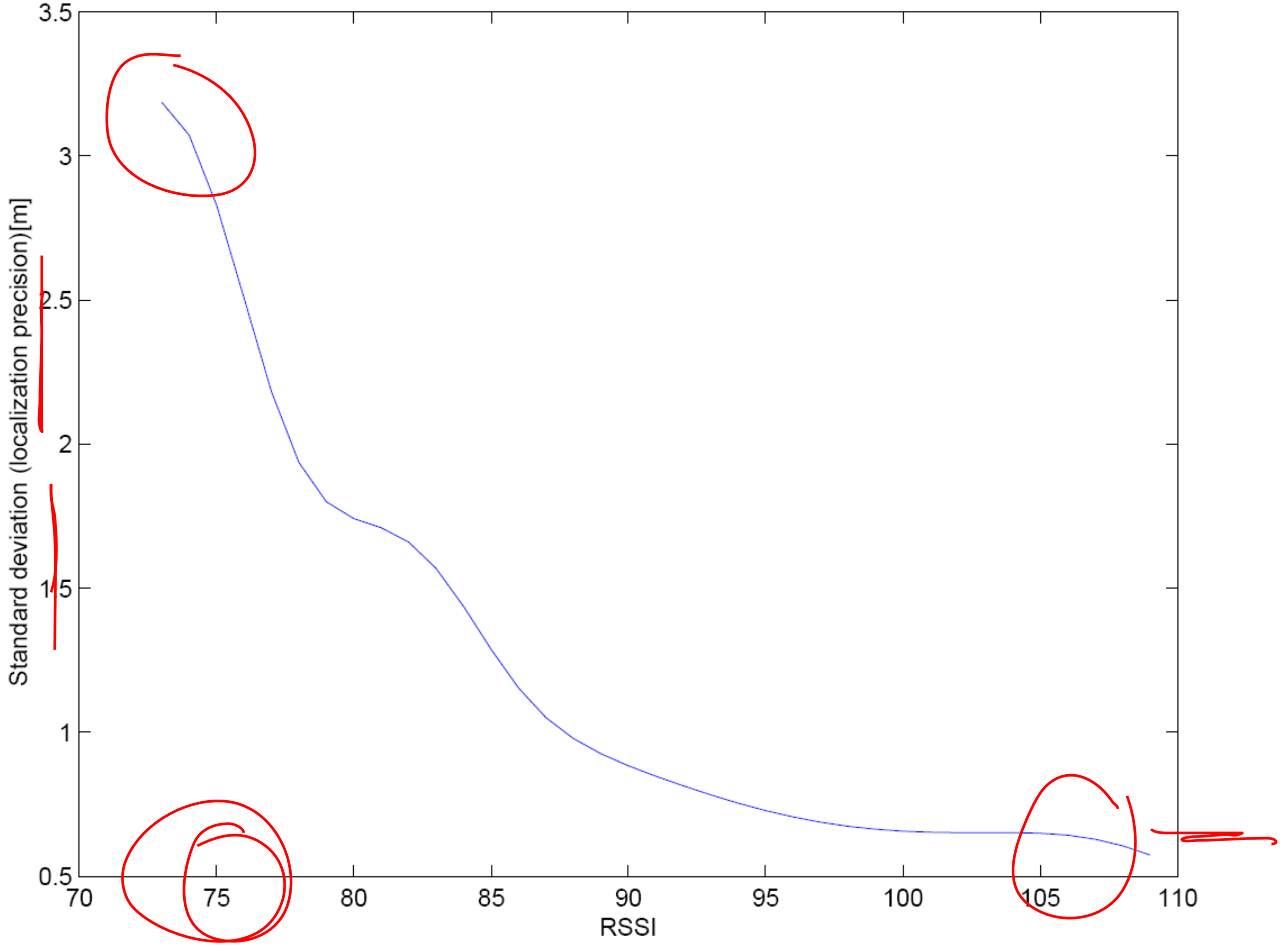


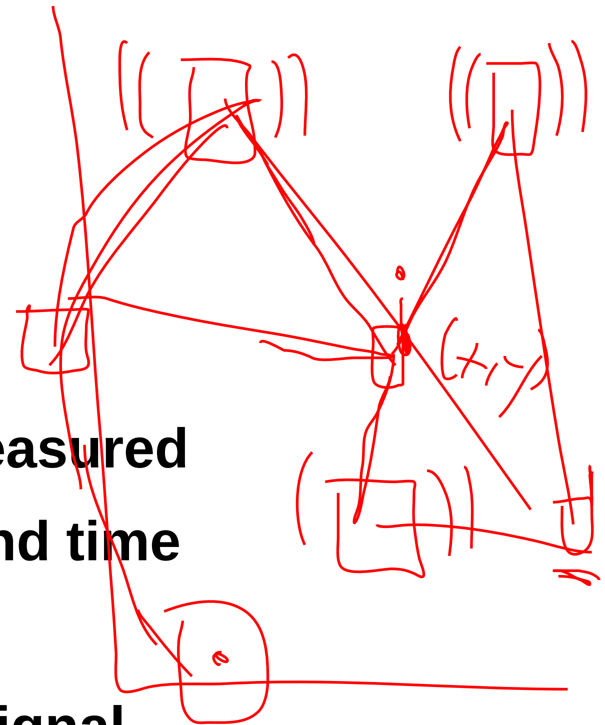
[Sichitiu and Ramadurai, MASS 2004]

Time of Arrival

$\Delta d = T - t$

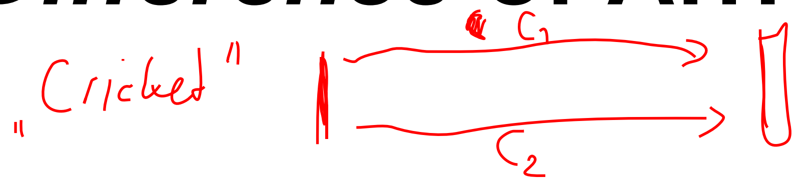
$\Delta d = \frac{d}{c}$

Trans. —Radio→ Rec.

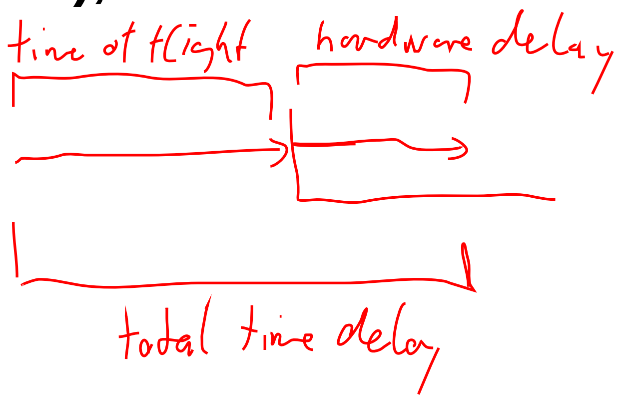


- Time of arrival (TOA)
  - Transmission time ("Time of flight") is measured
  - Transmission time = Reception time – Send time
  - Results from the quotient:
    - Transmission time = distance / speed signal
- Problem
  - Positions of measurement points (anchors) ~~must~~ do not need be known (~~usually~~...)
    „Anchor-free Localization“
  - Accurate time measurement
  - Clock synchronization
  - Relative ranges require more anchors

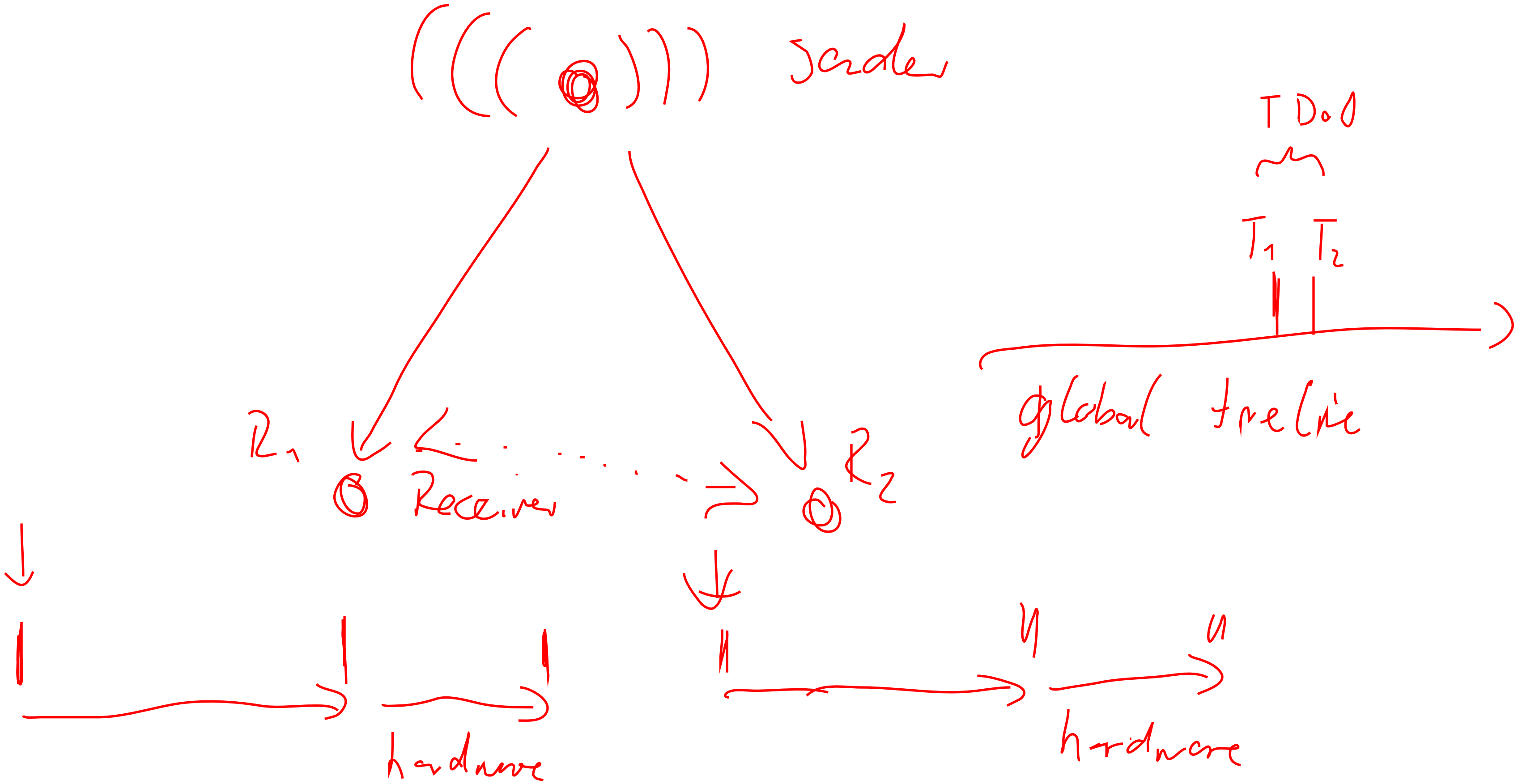
Time *Difference* of Arrival (ToA)



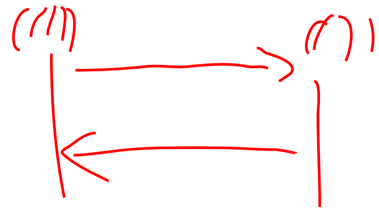
- **Two different signals with different transmission speeds**
  - **E.g. ultrasound and radio signal, "thunderstorm"**
  - **Main component of the speed of sound**
  - **Calculate the different arrival times is distance**
  - **If one signal is very fast (e.g. "light"), eliminate it**
- **Problems:**
  - **calibration (hardware delay)**
  - **special hardware is required**



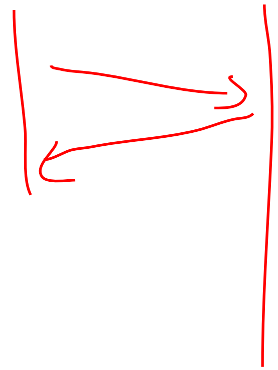
Time Difference of Arrival #2 (TDoA)



Round Trip time (ToA)

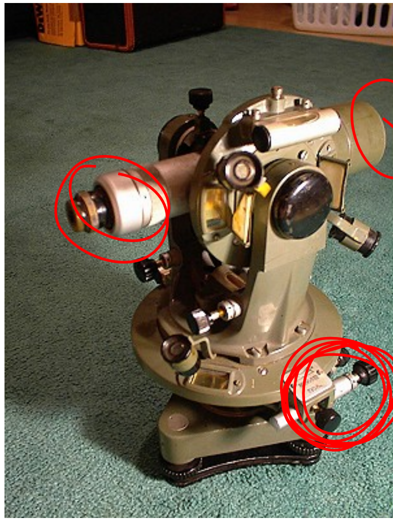


- **Two way communication, send a signal back and forth between two transceivers**
  - **E.g. radio signal, sound signal**
  - **Distance = 1/2 * Round trip time / c**
- **Problems:**
  - **Again: calibration (hardware delay)**
  - **Requires two transmitters and two receivers**
- **Similar: Measure distance to an obstacle (reflection)**
  - **Distance measurement by Laser or ultrasound**

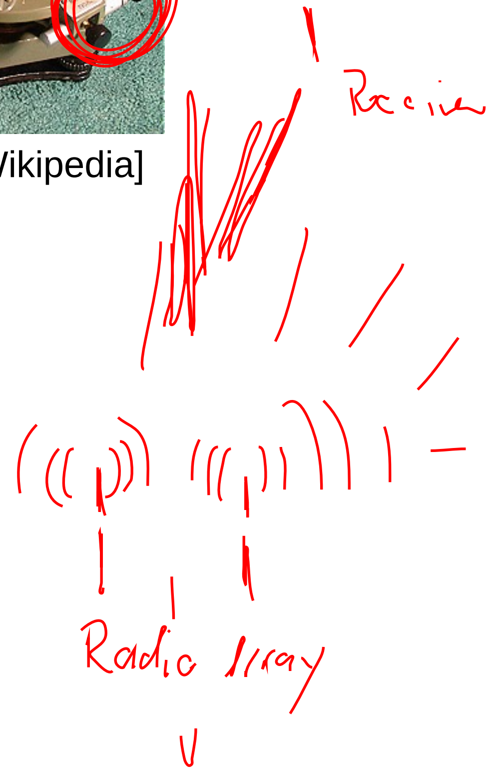


Determination of Angles

- Optical angle measurement
  - done manually, sextant, theodolite
- laser beams
  - maximum accuracy
  - Controlled by rotating mirrors
- Directional antennas „Beamforming"
  - free joint-directional or MIMO
    parabolic antennas
- Smart Antennae (antenna array)
  - (still) low precision (up to 1-2 degrees)
- Gyroscope

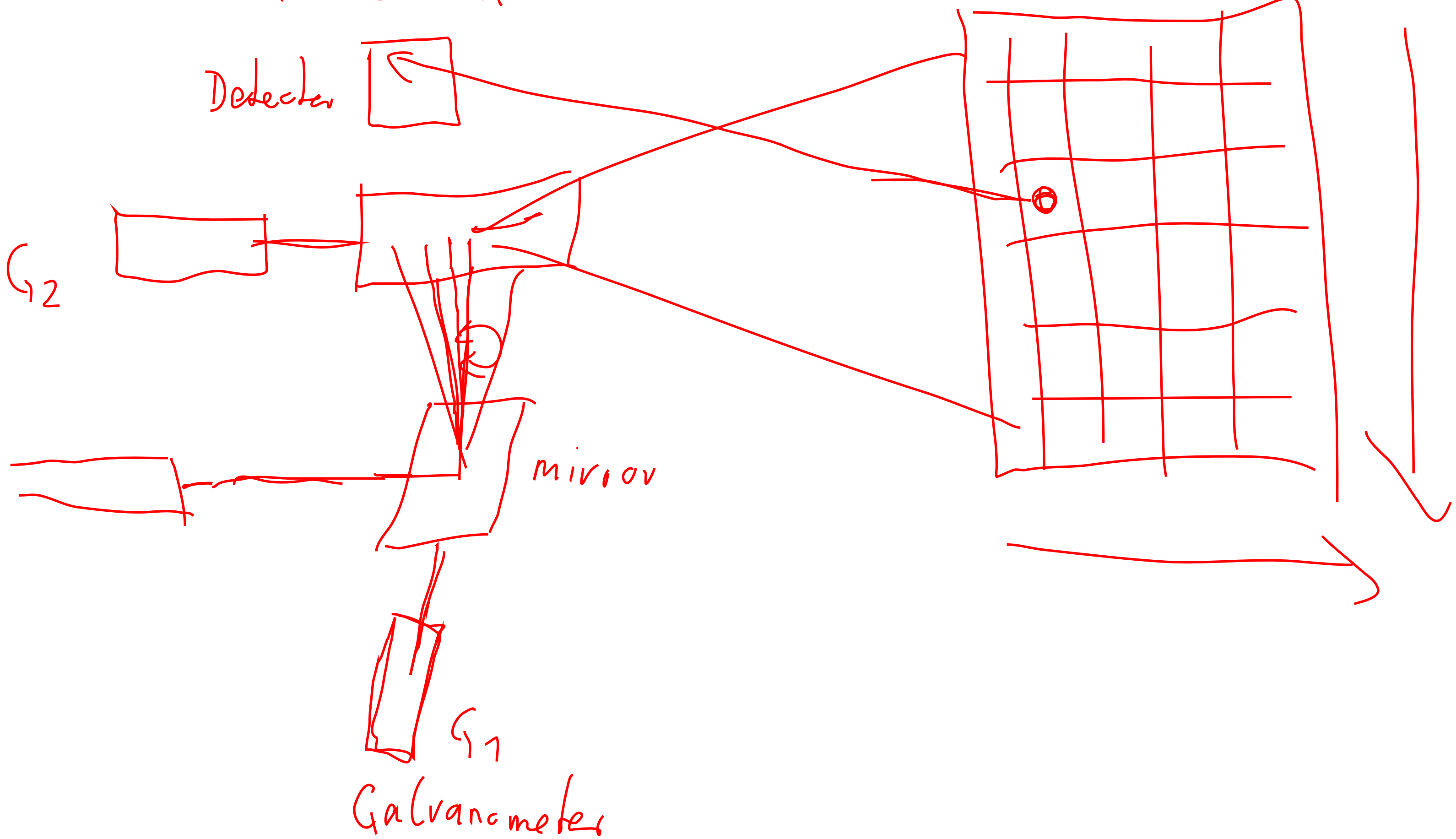


[Wikipedia]



IMTEK / EMP

Ga Locate



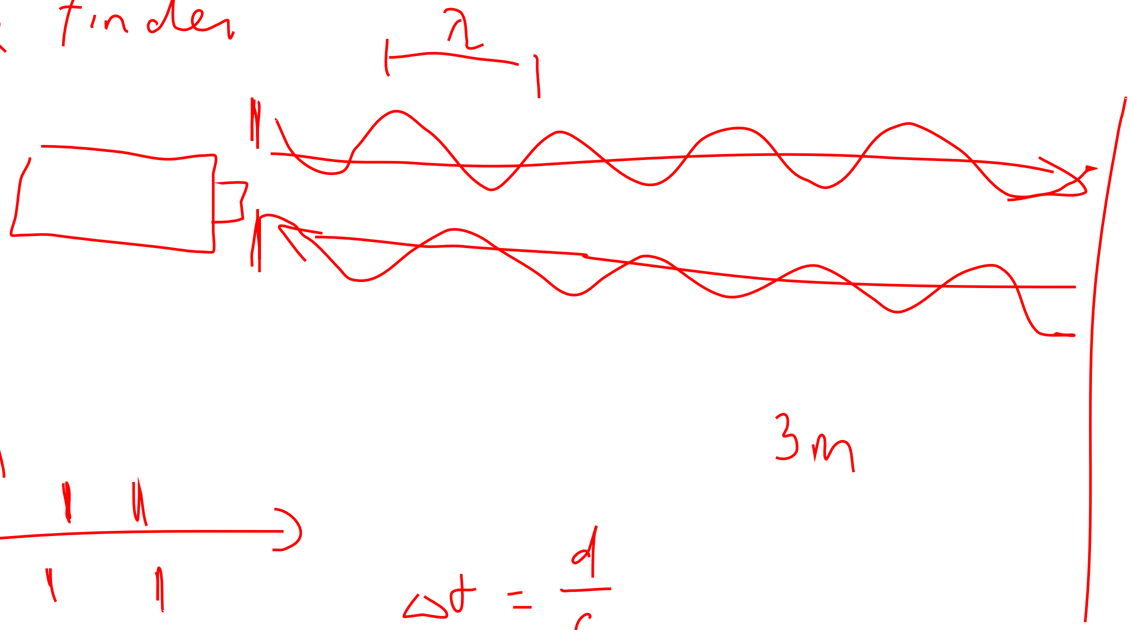
Determination of Ranges

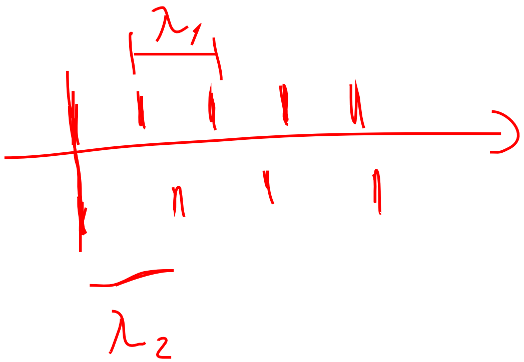
- **Measuring tape**
- **Laser range finders: Measure phase shift**
- **Laser scanners: Depth imaging**
- **RF ranging: Radar**
- **Optical: ToF camera**

[Würth, 2010]

[Sick, 2014]

Laser range finder





$$\Delta t = \frac{d}{c}$$

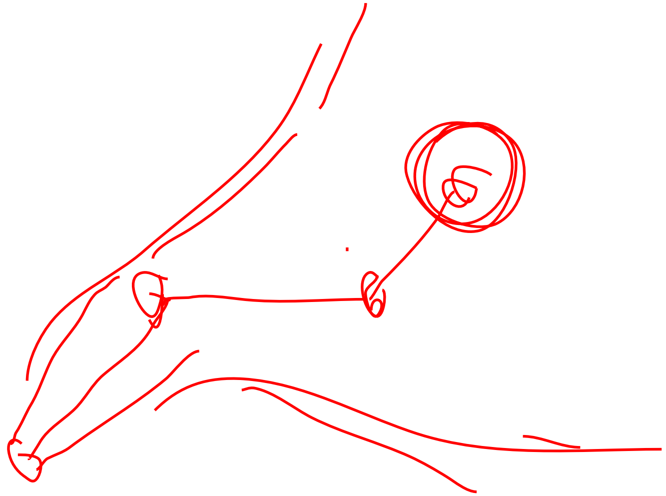
$$c = 300.000.000 \ \frac{m}{s}$$

10 ns

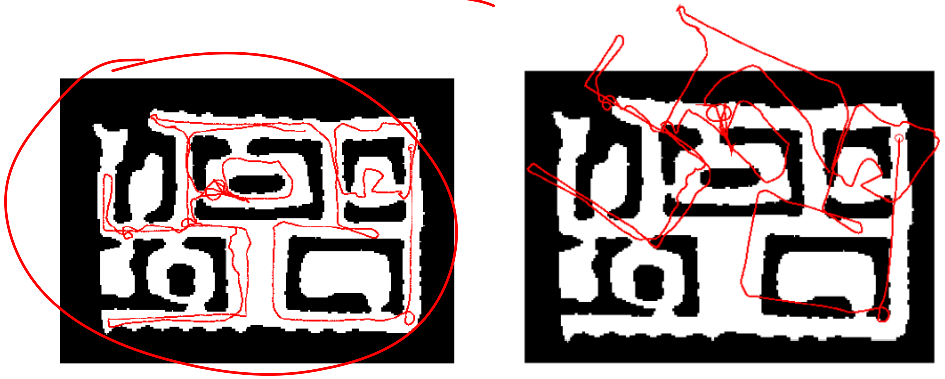
$\frac{1}{100}\ \mu s$

$\frac{1}{100\ \cancel{000}\ \cancel{000}}$

Odometry



- Measurement of travel distance
  - number of footsteps
  - odometer of a wheeled machine,
  - Mobile robot: Monitor individual wheels and steering angle
  - optical flow of vision / camera
- Integrate trajectory from a starting point ("dead reckoning")
- Problems:
  - Foot step size, wheel slip, different diameter of wheels
  - Error grows over time



[AIS, University of Freiburg]

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